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## **A Short-Range Locator System for Detecting Trapped Miners**

**By William E. Webb, R. H. Church,  
Walter E. Pittman, Jr., and James R. Boyle, Jr.**



**UNITED STATES DEPARTMENT OF THE INTERIOR**

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**UNITED STATES DEPARTMENT OF THE INTERIOR**  
**William P. Clark, Secretary**

**BUREAU OF MINES**  
**Robert C. Horton, Director**

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## CONTENTS

|  | <u>Page</u> |
|--|-------------|
| Abstract.....                                | 1           |
| Introduction.....                            | 2           |
| Technical background.....                    | 3           |
| Short-range locator system requirements..... | 3           |
| Range.....                                   | 3           |
| Frequency.....                               | 4           |
| Power supply.....                            | 4           |
| Cost.....                                    | 4           |
| Worker acceptance.....                       | 4           |
| Design of transmitters.....                  | 4           |
| Test results.....                            | 6           |
| Propagation through air.....                 | 6           |
| Propagation through air-rock path.....       | 7           |
| Propagation through rock.....                | 9           |
| Underground test.....                        | 13          |
| Prototype transmitter.....                   | 13          |
| Additional features.....                     | 14          |
| Battery conservation circuit.....            | 14          |
| Personal coding.....                         | 16          |
| Rescue team units.....                       | 16          |
| Safety considerations.....                   | 17          |
| Permissibility.....                          | 17          |
| Ignition of blasting materials.....          | 17          |
| Conclusions.....                             | 17          |
| Bibliography.....                            | 18          |

## ILLUSTRATIONS

|   |    |
|---|----|
| 1. Schematic representing 660-kHz AM transmitter (unit 1).....                                  | 5  |
| 2. Schematic representing 27-MHz transmitter (unit 2).....                                      | 5  |
| 3. Schematic representing 27-MHz power amplifier (unit 3).....                                  | 5  |
| 4. Schematic representing 27- to 60-MHz transmitter.....  | 6  |
| 5. Unit 1 being placed in box.....  | 8  |
| 6. Overburden being placed over transmitter.....  | 8  |
| 7. Test holes being drilled.....  | 10 |
| 8. Plan and elevation view of test holes at the Nickel Plate site.....                          | 10 |
| 9. Plan and elevation view of test holes at the Drummond site .....                             | 10 |
| 10. Transmitter being lowered into test hole.....   | 11 |
| 11. Signal strength measurements being taken at toe of highwall.....                            | 11 |
| 12. Typical plot of signal strength versus range through rock.....                              | 12 |
| 13. Plot of signal strength versus range for airpath.....                                       | 12 |
| 14. Schematic representing underground test location.....                                       | 13 |
| 15. Transmitter placed inside cap lamp battery.....   | 14 |
| 16. Schematic diagram of cap lamp transmitter.....  | 15 |
| 17. Cap lamp battery voltage versus time of discharge.....                                      | 15 |
| 18. Schematic diagram of low-voltage sensor.....  | 15 |
| 19. Low-voltage sensor operational setup.....   | 15 |
| 20. Cap lamp battery voltage versus time with automatic shutdown of low-<br>voltage sensor..... | 16 |
| 21. Light sensor output volts with low-voltage sensor.....                                      | 16 |

## TABLES

|   | <u>Page</u> |
|---|-------------|
| 1. Transmitter signal range in air, unit 2.....   | 7           |
| 2. Signal range of transmitter covered with varying thicknesses of rock,<br>unit 2..... | 7           |

## UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

|            |                   |          |            |
|------------|-------------------|----------|------------|
| A          | ampere            | $\mu$ H  | microhenry |
| dB/m       | decibel per meter | MHz      | megahertz  |
| ft         | feet              | min      | minute     |
| g          | gram              | mV       | millivolt  |
| h          | hour              | $\mu$ V  | microvolt  |
| Hz         | hertz             | mW       | milliwatt  |
| in         | inch              | $\Omega$ | ohm        |
| kHz        | kilohertz         | pct      | percent    |
| k $\Omega$ | kilohm            | pF       | picofarad  |
| mA         | milliampere       | V        | volt       |
| $\mu$ F    | microfarad        | W        | watt       |
| mH         | millihenry        |          |            |

# A SHORT-RANGE LOCATOR SYSTEM FOR DETECTING TRAPPED MINERS

By William E. Webb,<sup>1</sup> R. H. Church,<sup>2</sup> Walter E. Pittman, Jr.,<sup>3</sup>  
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## ABSTRACT

As part of the Bureau of Mines health and safety research program, a short-range locator system, capable of locating miners who have become trapped following a mine accident, has been devised. The system consists of a lightweight, low-power radio transmitter incorporated into a miner's cap lamp battery and a directional receiver carried by rescuers. Prototype transmitters have been constructed, and the propagation of their signals has been investigated. The detectability of the signal in underground coal mines has also been investigated. This research indicates that a short-range location system would serve as an economical and practical means of locating miners from within the mine following an accident.

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## INTRODUCTION

Experience in postdisaster rescue work has indicated a need for a reliable means of quickly locating trapped miners. This was particularly evident after the 1968 explosion at the Consol No. 9 Mine in Farmington, WV, where the whereabouts and condition of 76 men were unknown. This event prompted the enactment of the Coal Mine Health and Safety Act of 1969. The tragedy at Farmington focused national attention upon the problems of mine safety, including those of postdisaster rescue.

At the request of the Bureau of Mines, the National Academy of Engineering created the Committee on Mine Rescue and Survival Techniques to "conduct a study program to assess the technological capabilities that can be applied to survival and rescue techniques following mine disasters." The Bureau was particularly interested in the possible application of new technology to the problem of mine safety. The Committee on Mine Rescue and Survival made many recommendations for research in communications and mine rescue. The suggestions in regard to communication systems led to several Bureau programs to investigate through-the-earth communications and trapped miner location systems.

Most of the work on electromagnetic location was directed toward devising relatively long-range systems for locating an underground transmitter from the surface. Although these systems would undoubtedly prove to be of great value in future rescue operations, they would likely have several limitations:

1. Owing to the expense and the weight added to the miner's personal equipment, it might not be economically or operationally feasible to equip every miner with a transmitter. Thus, the availability of the transmitter to the trapped miner would be uncertain.

2. The trapped miner would have to take some action, such as deploying an antenna, that might be impossible if the miner were injured or confined.

3. Since highly specialized location equipment would be required, it is possible that 24 to 48 h would be needed to move the system to the site of a disaster and deploy it. Because of these limitations, it is believed that a lightweight, inexpensive, short-range location system for use underground is needed to complement the long-range (underground to surface) systems being studied.

The short-range system devised by the Bureau consists of a low-power radio transmitter carried by each miner as an integral part of the cap lamp battery pack, capable of being detected by a simple receiver utilized by the rescue team. The transmitter has a range of 100 to 200 ft and would operate continuously, so that activating the system would require no action on the part of the trapped miner. Following a disaster, the transmitter would serve as a radio beacon to help rescue personnel and locate trapped miners under or behind roof falls or barricades, or in other inaccessible places. It is believed that such a system would enhance the chance of postdisaster survival by reducing the time required to locate trapped and possibly injured personnel. Rapid location of victims has the added advantage of reducing the time rescue personnel are exposed to a potentially hazardous environment. Thus, the locator could be a significant factor in enhancing the safety of the rescue team even in cases where the victims failed to survive the initial accident.

This report describes the design and testing of a short-range radiofrequency location system that could be housed in the miner's cap lamp and powered from the cap lamp battery. The locator is intended as an inexpensive add-on to the cap lamp and has been designed so that it can be retrofitted into existing battery cases. Questions of technical and economic feasibility, worker acceptance, and permissibility are addressed.

An extensive review of current state-of-the-art location systems has been compiled and is presented as a comprehensive bibliography.

## TECHNICAL BACKGROUND

The 1970 report of the National Academy of Engineering recognized that there were two aspects to the problem of trapped miner location. The first problem was to locate the trapped miner from the surface so that rescue efforts could be initiated and directed toward the proper area in the mine. The second problem was to guide rescue teams to trapped or injured miners who might be within a few feet but buried under rock or obscured by smoke or debris. It was first assumed that one system could serve both functions, but early work soon indicated that the requirements for the two applications were largely incompatible. The long-range locator requires a low-frequency (kilohertz) transmitter with sufficient power to be capable of penetrating hundreds of feet of rock and soil. The short-range locator should be small and lightweight so that it can be carried on the miner's person; therefore, it must be low power and operate at a high frequency (megahertz). It is clear that two separate systems are required.

One approach to the short-range locator would be to use a passive system, similar to that used for security in libraries and retail stores. The passive locator consists of an antenna and a nonlinear element, usually a diode or ferromagnetic element. The device is irradiated at one frequency but because of the nonlinearity, is capable of generating and re-radiating a different harmonic frequency.

### SHORT-RANGE LOCATOR SYSTEM REQUIREMENTS

The short-range locator (SRL) is intended to serve as a personal beacon to aid rescue personnel in locating trapped miners in a postdisaster environment. Discussions were held with Bureau, Mine Safety and Health Administration (MSHA), company, and union officials as to what constitutes an effective SRL. Since every miner would be provided with an SRL, the transmitter must be extremely small, lightweight, and inexpensive. Some of the factors considered in the design of the SRL were range, frequency, power supply, cost, and worker acceptance (size and weight).

The passive transponder would be worn by the miner. The rescue team would carry a transmitter and receiver tuned to the appropriate harmonic. When near a transponder, a signal would be detected by the rescue team receiver.

During the early stages of this project, a survey was made of the commercially available passive transponders, so that an existing commercial system could be modified for use underground. The existing passive systems were found to be limited to ranges of a few feet at most, and within limitations of practical size and transmitter power, the range could not easily be extended. It also soon became apparent that a passive system was not likely to be useful in the electromagnetic noise environment of a typical mine.

An alternative to the passive transponder would be either an active beacon or an active transponder. The transponder would have the advantage of only transmitting when it was interrogated. It would therefore be less of a source of electromagnetic interference than would a continuously operating beacon. On the other hand, the transponder would require considerably more complex circuitry. It was determined that the advantages of a transponder would not justify the additional size and expense, and that an active beacon was the most realistic technical approach.

### RANGE

The SRL system should be able to operate over a range of at least 100 ft in air and through 10 or more feet of rock. This range would be adequate in most post-mine-disaster scenarios that can be envisioned. Slightly greater ranges might be desirable; however, the range should not be too great, in order to avoid interference between different transmitters.



## FREQUENCY

The operating frequency of the SRL is a compromise between several constraints. In general, lower frequencies propagate better through the ground but require larger, heavier units. High-frequency transmitters have the advantage of using smaller components and requiring shorter antennas, thereby allowing use of the cap lamp cord as an antenna. Another factor to be considered is that at certain frequencies the mine tunnels may act as dielectric wave guides. The determination of the optimum frequency of operation was one of the objectives of this project.

## POWER SUPPLY

As designed, the SRL is powered by and incorporated into the miner's cap lamp battery. This is desirable since a separate power source would more than double the weight of the transmitter. Also, using the cap lamp battery eliminates the maintenance required to keep a separate battery charged or periodically replaced. The lamp battery is always fully charged at the beginning of each shift. It should be noted that the power consumed by the SRL will be negligible compared with that used by the cap lamp and, therefore, will not significantly reduce the length of time that the lamp will operate between rechargings.

## DESIGN OF TRANSMITTERS

SRL transmitters were constructed to operate at 660 kHz, 27 MHz, 45 MHz, 50 MHz, and 60 MHz.

The 660-kHz transmitter (unit 1) is shown schematically in figure 1. It employed a single 2N222 transistor as an inductively coupled oscillator and a single-stage power amplifier. The oscillator was amplitude modulated by switching its collector supply with the 555 timer (integrated circuit (IC)-2). The original transmitter produced a steady audio tone at 940 Hz. Early tests showed that the steady tone was not easily detected and could be confused with the

The main disadvantage of using the cap lamp battery is that it requires the transmitter to operate on 4-1/2 V. While this is not an insurmountable obstacle, a slightly higher voltage would simplify circuit design.

## COST

Since each miner would be equipped with an SRL transmitter, it is necessary that they be inexpensive. Here again the use of the cap lamp battery eliminates the expense of both a second battery and a separate case. It was estimated that an SRL transmitter could be incorporated into a cap lamp at approximately \$10 additional cost for each unit, based upon component cost and circuitry.

## WORKER ACCEPTANCE

The SRL would be very small and lightweight so as not to encumber the miner with additional equipment. The prototype SRL weighed 67 g; it was implemented with discrete components and could be repackaged into a much smaller integrated circuit. Incorporating the SRL into the cap lamp battery pack would not make the miner aware of its presence. The unit would operate continuously and would require no action on the part of the miner. This would avoid the possibility of a worker's forgetting to turn on the unit when going underground or of its being turned off accidentally.

beat note that resulted when the receiver was tuned slightly off a distant station. A second 555 timer (IC-1) was therefore used to modulate IC-2. This circuit produced a wavering tone that switched between 235 and 940 Hz at a rate of about 0.6 Hz. This tone proved to be quite easy to detect audibly and could not be confused with any type of interference.

The 27-MHz transmitter (unit 2) is shown in figure 2. It employed two ECG222 field effect transistors (FET's), one as a crystal-controlled oscillator and the other as an emitter follower to drive the antenna. The antenna

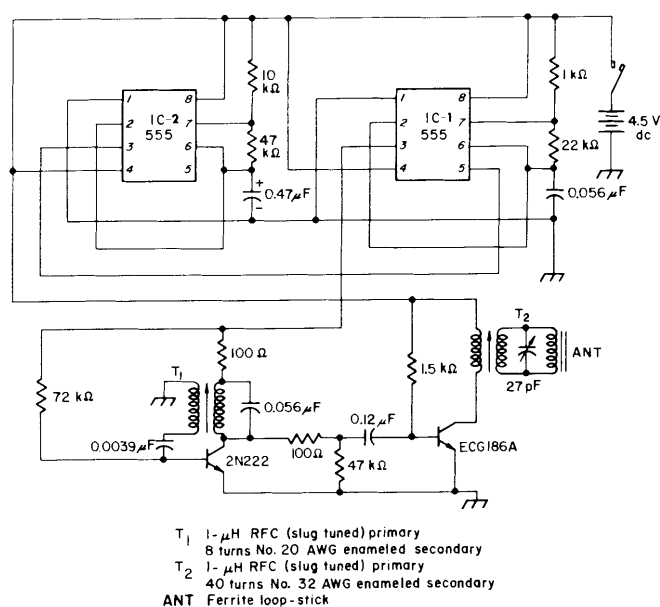


FIGURE 1. - Schematic representing 660-kHz AM transmitter (unit 1).

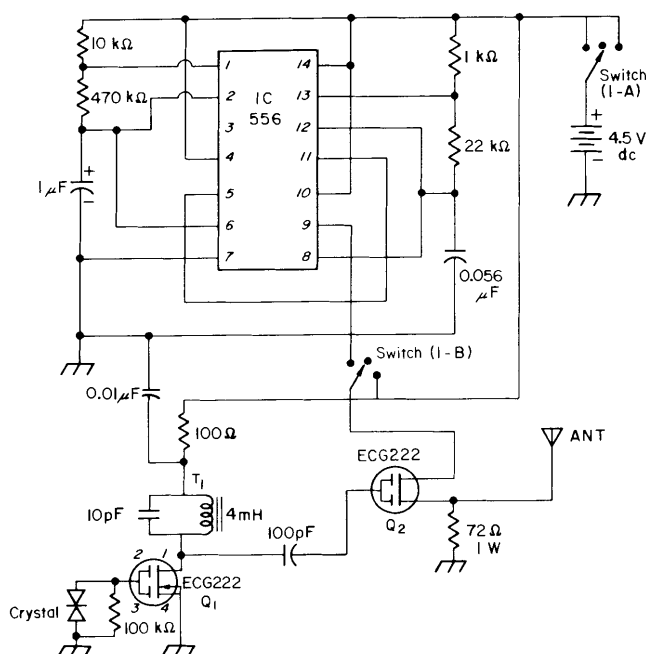


FIGURE 2. - Schematic representing 27-MHz transmitter (unit 2).

was a wire approximately 6 ft long. In this circuit, the two 555 timers were replaced with a single 556 dual timer. It was found that performance was improved by operating the oscillator from a constant supply and modulating the emitter follower. A switching arrangement was provided so that either the wavering tone or an unmodulated carrier could be transmitted.

A second 27-MHz transmitter (unit 3) was identical to unit 2 except for the addition of one stage of power amplification. The output amplifier, shown in figure 3, used a single ECG186A power transistor operated as a class B power amplifier.

A transmitter capable of operating throughout the range of 27 to 60 MHz was also constructed. This transmitter (unit 4) is shown schematically in figure 4. A crystal oscillator drove a single-transistor output amplifier. The amplifier was modulated by the 556 timer. Switch 1-A allowed either a modulated signal (beep) or unmodulated carrier to be selected. The operating frequency was selected by changing the plug-in oscillator coils and/or crystals. Available frequencies were 26.995, 40.000, 45.000, 50.000, and 60.000 MHz.

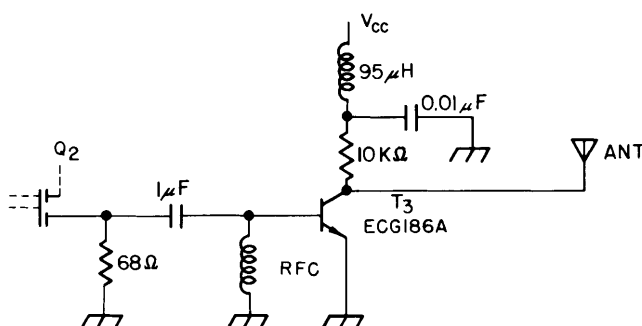


FIGURE 3. - Schematic representing 27-MHz power amplifier (unit 3).

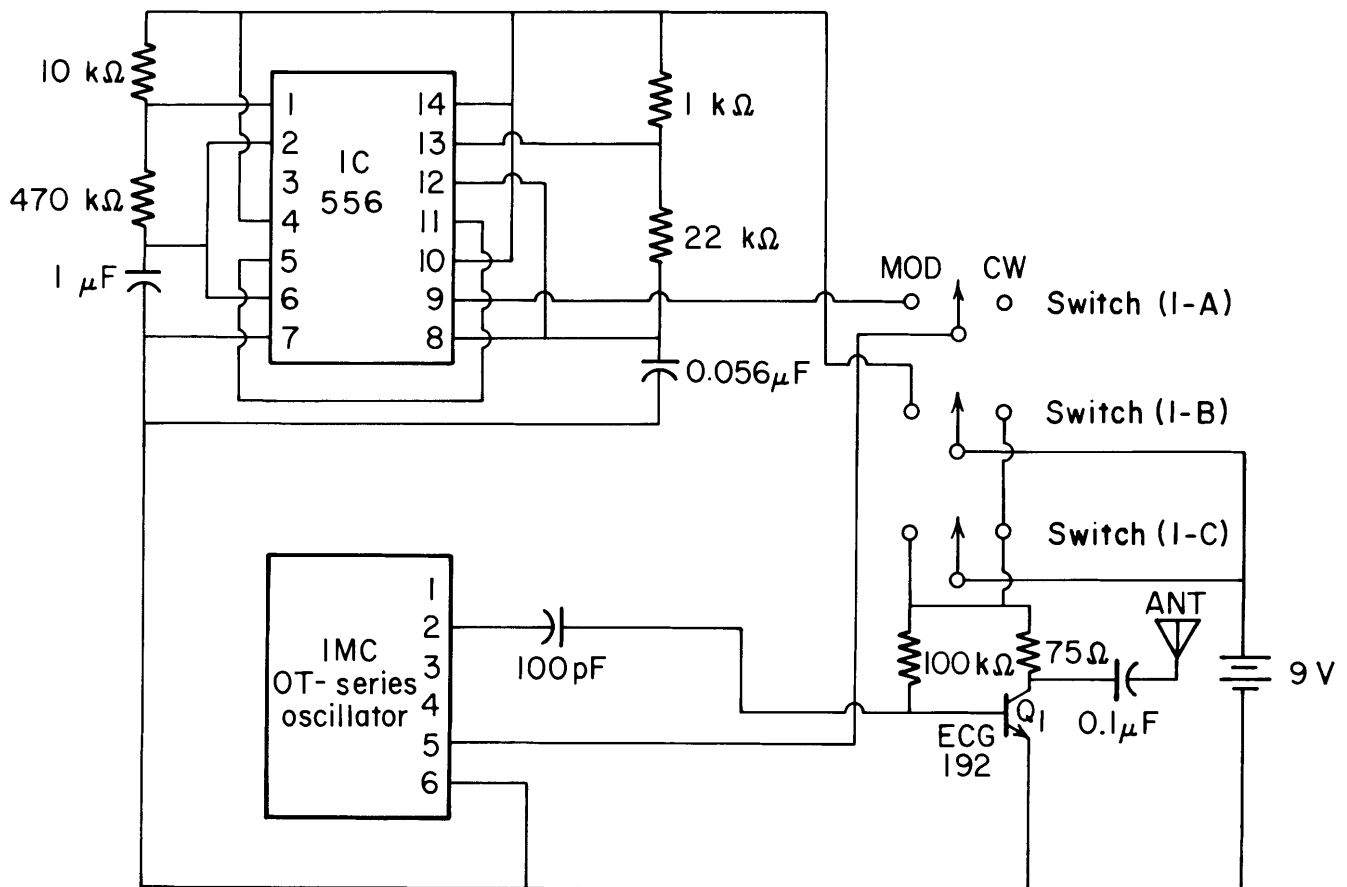


FIGURE 4. - Schematic representing 27- to 60-MHz transmitter.

#### TEST RESULTS

Four tests were conducted to evaluate the performance of the prototype SRL transmitter. These tests consisted of--

1. Measurement of the signal strength propagation through air;
2. Measurement of the signal strength propagation through air and broken rock;
3. Measurement of the propagation through solid rock;
4. Measurement of propagation underground.

#### PROPAGATION THROUGH AIR

The approximate range of the transmitter in air was determined by detecting

the signal with a multiband communications receiver. The 660-kHz transmitter (unit 1) was found to have a range of approximately 60 ft when placed directly on the ground. This could be extended to several hundred feet by connecting a 20-ft wire antenna to the end of the ferrite loopstick antenna. The poor performance of this transmitter was attributed to the combination of low power and inefficient antenna. The 27-MHz transmitters (units 2 and 3) could be detected at distances of approximately 3,300 to 5,000 ft, with the transmitter located at about a 30-ft elevation. Table 1 shows typical results through the air for a handheld 27-MHz transmitter (unit 2). Although the field strength voltage fell below 40 μV at 600 ft, the tone was still audible

for 1,500 ft. The unit 4 transmitter could be detected at ranges of up to 1 mile.

TABLE 1. - Transmitter signal range in air, unit 2 (27 MHz)

| <u>Distance</u><br><u>in air, ft</u> | <u>Field</u><br><u>strength, <math>\mu V^1</math></u> |
|--------------------------------------|---|
| 77.....                              | 775   |
| 124.....                             | 455   |
| 166.....                             | 145   |
| 215.....                             | 135   |
| 260.....                             | 109   |
| 300.....                             | 86  |
| 345.....                             | 66  |
| 400.....                             | 84  |
| 480.....                             | 69  |
| 515.....                             | 42  |
| 601.....                             | 28  |

<sup>1</sup>Background noise  $\approx 32 \mu V$ .

#### PROPAGATION THROUGH AIR-ROCK PATH

To evaluate the performance of the SRL through a propagation path similar to one that might be encountered after a roof fall, the transmitters were buried under a pile of broken rock, and the range at which the signal was just detectable was measured at various depths of the debris thickness.

The tests were conducted at a coal surface mining operation in Tuscaloosa County, AL. The prototype transmitters were enclosed in a wooden box to prevent damage (fig. 5). Each transmitter in turn was enclosed in the box, placed on the floor of the strip pit, and covered with overburden consisting of broken shale and fire clays (fig. 6).

For unit 1 (660 kHz), no decrease in the signal strength or range was detected for broken rock coverings of 10 ft. Typical results for a 27-MHz transmitter (unit 2) through the air-rock path are shown in table 2.

TABLE 2. - Signal range of transmitter covered with varying thicknesses of rock, unit 2 (27 MHz)

| <u>Thickness</u><br><u>of rock, ft</u> | <u>Maximum</u><br><u>range, ft<sup>1</sup></u> |
|--|--|
| 0.....                                 | 835  |
| 0.9.....                               | 750  |
| 1.7.....                               | 720  |
| 2.3.....                               | 670  |
| 4.3.....                               | 400  |
| 6.7.....                               | 350  |
| 8.0.....                               | 350  |
| 9.0.....                               | 350  |
| 10.0.....                              | 350  |

<sup>1</sup>Air path plus rock thickness.

As a test of the validity of these results, they were fitted to an equation of the form

$$S_m = \frac{P_o}{4\pi R^2} \epsilon - \alpha d, \quad (1)$$

where  $P_o$  = effective radiated power at the transmitter,

$S_m$  = minimum detectable signal power,

$R$  = range, combined air-rock path,

$\alpha$  = attenuation coefficient of rock,

and  $d$  = rock thickness.

Equation 1 can be written

$$U = \alpha d + k, \quad (2)$$

$$\text{where } U = -2 \ln R, \quad (3)$$

$$\text{and } k = \ln \frac{4\pi S_m}{P_o}. \quad (4)$$

A linear regression of  $d$  on  $U$  gave an excellent fit, with a value of  $\alpha$  of 2.6 dB/m from the broken rock.

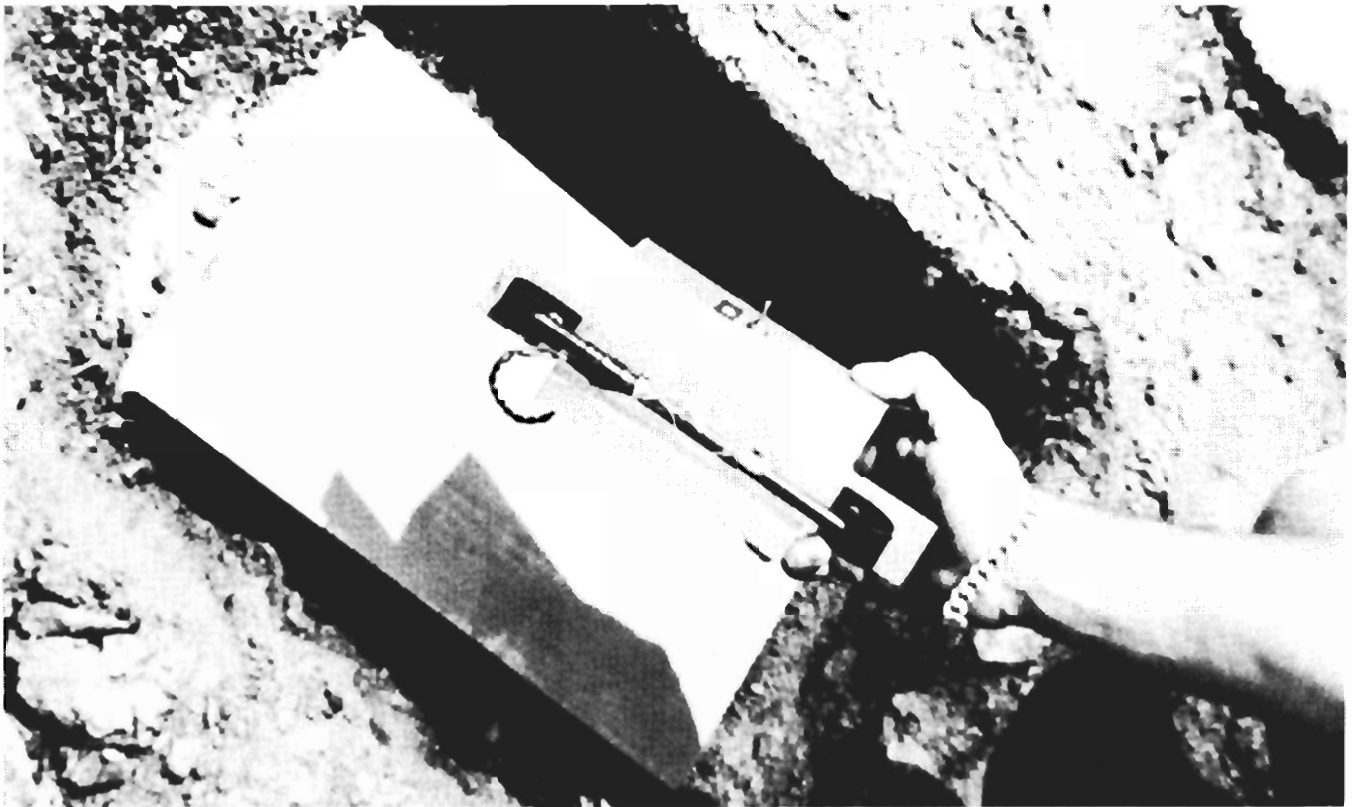


FIGURE 5. - Unit 1 being placed in box.



FIGURE 6. - Overburden being placed over transmitter.

## PROPAGATION THROUGH ROCK

To measure the propagation through solid rock, tests were conducted at the Nickel Plate Mining Co., Inc. Pit No. 3 in Jefferson County, AL, and at Drummond Coal Co. Kellerman Pit in Tuscaloosa County, AL. At each site a series of vertical holes 6-3/4 in. in diameter and 50 ft deep were drilled along a line extending at 45° back from the highwall (fig. 7). Location of the holes at the Nickel Plate and Drummond sites are shown in figures 8 and 9, respectively. The transmitter was lowered into each hole to a depth level with the floor of the pit, and the signal was measured at the face of the highwall. Figure 10 shows the transmitter, enclosed in a plastic case to protect it from water and dirt, being lowered into a test hole. Figure 11 shows signal strength measurements being made.

The signal strength meter consisted of a commercial communications receiver that was modified by disconnecting the squelch control and adding a meter to read the automatic gain control (AGC) voltage. The meter was calibrated by injecting into the receiver a signal of known amplitude from a VHF signal generator. Signal levels from 0.1  $\mu$ V to 20 mV were used. Since the AGC voltage is a nonlinear function of the receiver signal, a computer program was written to convert the meter reading to signal strength. This program used a four-point interpolation on the stored calibration curve. The sensitivity of the signal strength meter was the same through all frequency tests, approximately 0.1  $\mu$ V.

To ensure that the measured signal was actually propagating through the rock and not leaking out of the tops of the holes, the signal strength was also measured above the holes. No signal was found once the transmitter had been lowered more than 20 ft into a hole, even with the hole open. As an added precaution the holes were covered with a metal plate while measurements were being made.

Several tests were conducted on the three 27-MHz transmitters (units 2, 3, and 4). It was found that at the Nickel Plate site the audio tone was strongly audible from station 4, a distance of 43.9 ft, and weak but clearly audible from station 5, a distance of 62.8 ft. A faint signal could sometimes be detected from stations 6 and 7, distances of approximately 95 and 110 ft. The useful range through solid rock was judged to be approximately 60 ft.

Tests at the Drummond site gave similar results. An audible signal could be detected from stations 1 through 5 (51.6 ft maximum rock thickness). Occasionally a faint signal could be heard at station 6 (62.6 ft). The apparent decrease in range was attributed to the higher moisture content of the rock at the Drummond site, as evidenced by water seeping from the face of the highwall. In order to verify this, core samples were collected at both sites. The Nickel Plate sample contained 1.5 pct moisture, the Drummond site 9 pct moisture. When signal strength measurements were made, the transmitter modulation was turned off and the strength of the unmodulated carrier measured at the face of the highwall. Usable data were obtained at stations 1 through 5 at each site.

To determine the attenuation coefficient of the rock, it was assumed that the power density (P) at the receiver was given by

$$P = \frac{G_T P_0}{4\pi R^2} - \alpha R, \quad (5)$$

where

R = range through rock,

P<sub>0</sub> = effective radiated power at the transmitter,

$\alpha$  = attenuation coefficient of rock

and

G<sub>T</sub> = antenna gain of the transmitting antenna in the direction of the receiver.



FIGURE 7. • Test holes being drilled.

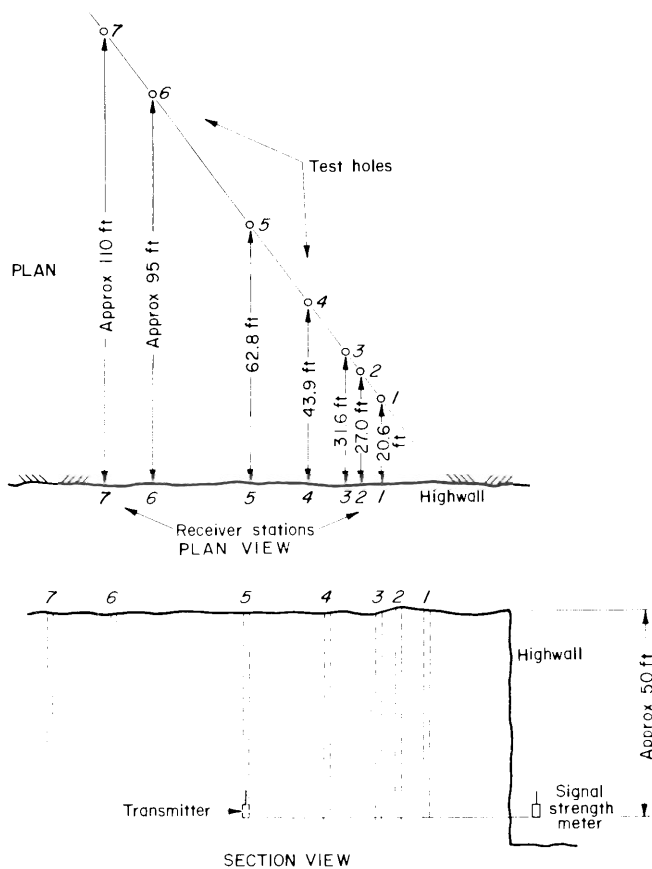


FIGURE 8. • Plan and elevation view of test holes at the Nickel Plate site.

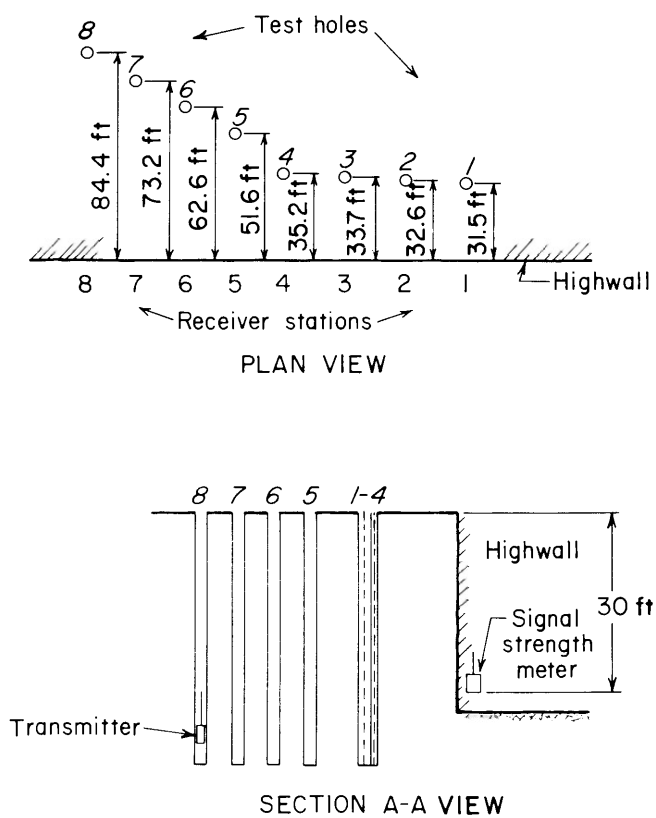


FIGURE 9. • Plan and elevation view of test holes at the Drummond site.



FIGURE 10. - Transmitter being lowered into test hole.



FIGURE 11. - Signal strength measurements being taken at toe of highwall.



The measured signal strength was proportional to the square root of the power density at the receiver, i.e.,

$$S = k \sqrt{G_R P}, \quad (6)$$

where  $G_R$  = receiver antenna gain,

and  $k$  = sensitivity factor for the receiver.

From equations 5 and 6,

$$S = \frac{S_0}{R} - \alpha R/2, \quad (7)$$

$$\text{or} \quad \ln(RS) = \ln S_0 - \frac{\alpha}{2} R. \quad (8)$$

Here,  $S_0$  is a constant involving  $G_R$ ,  $G_T$ , and  $k$ . Care was taken to keep the orientation of the transmitter and receiver antenna the same for all measurements so that  $S_0$  would not vary.

The signal voltages were fitted to equation 8, and from this the best value of  $\alpha$  was determined. In general, the experimental data fit this equation extremely well despite the fact that the "far field" assumption implied in its derivation was not strictly met by the actual experimental geometry. A typical plot of signal strength versus range is shown in figure 12. The data points are the measured field strengths; the solid line is the best fitting theoretical curve. For comparison, a plot for propagation in air is shown in figure 13. The measured attenuation coefficient for the airpath was 0.0001 (essentially zero), which added considerable confidence in the data reduction technique.

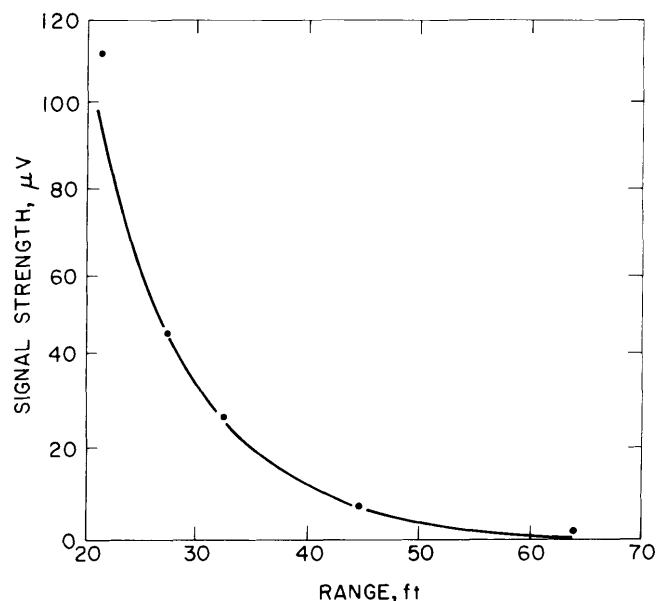


FIGURE 12. - Typical plot of signal strength versus range through rock.

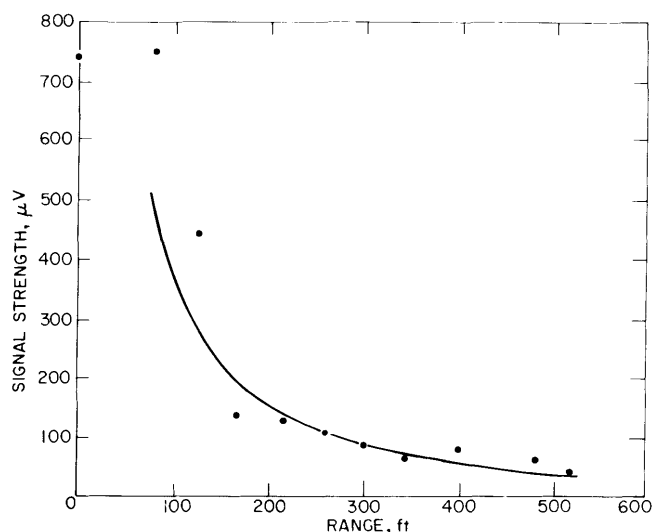


FIGURE 13. - Plot of signal strength versus range for airpath.

Data from the Nickel Plate site fit the theoretical curve exceptionally well, the average error at a point being less than 6 pct. The attenuation coefficient was found to be  $1.93 \pm 0.02$  dB/m. Data from the Drummond site were less reliable. The value of the attenuation coefficient could not be determined with any precision, but it appeared to be at least twice as large as at the Nickel Plate site.

Unit 4 transmitters were also tested at higher frequencies at both sites. At the Nickel Plate site, an audible signal from station 1 (20.6 ft) and occasionally a weak signal from station 2 (27.0 ft) could be detected, indicating that the attenuation is much greater in the 45- to 60-MHz range than at 27 MHz. No detectable signal was obtained at the Drummond site, where the minimum rock thickness was 31.5 ft. Reliable measurement of attenuation coefficient in the 45- to 60-MHz range could not be obtained.

#### UNDERGROUND TEST

A 27-MHz transmitter was taken underground to determine the range. The test was conducted at the North River Energy Corp. No. 1 Mine in Fayette County, AL. The transmitter was placed in an entry, and the maximum distance at which it could be detected was determined. Measurements were made both down the entry

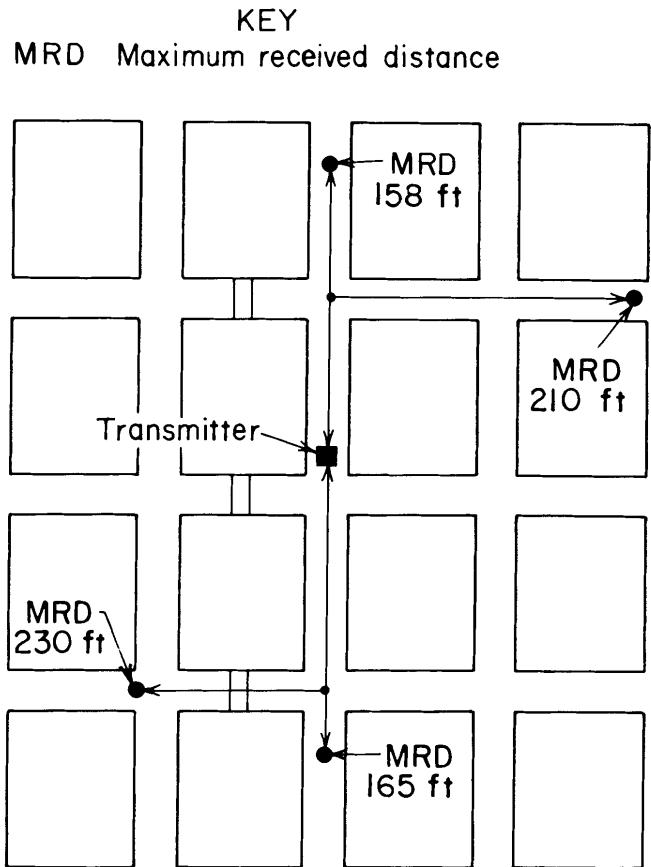


FIGURE 14. - Schematic representing underground test location.

and in crosscuts. The maximum distance ranged from 158 to 230 ft as shown in figure 14.

#### PROTOTYPE TRANSMITTER

A demonstration transmitter (fig. 15) was constructed and incorporated into a miner's cap lamp battery. The circuit (fig. 16) is essentially the same as that of the unit 2 transmitter used in the propagation tests. RFC1 and RFC2 are inductors to isolate the RF circuits and lamp cord (which serves as an antenna) from the battery. No modification to the lamp was required.

This unit exhibited open-air and underground ranges comparable to those of the other 27-MHz transmitters. This frequency allowed for use of the cap lamp cord as an antenna, thereby significantly affecting circuit simplicity, and allows for use of conventional CB broadband receivers that are approved as intrinsically safe.

## ADDITIONAL FEATURES

## BATTERY CONSERVATION CIRCUIT

When a lead sulfate battery, such as a cap lamp battery, is discharged by a constant resistance load, the terminal voltage decreases slowly and almost linearly with time until it reaches 85 to 90 pct of the fully charged value. At this point, the battery begins to enter the deep-discharge condition and the terminal voltage falls rapidly to near 0 V, as shown in figure 17. This means that a cap lamp that is initially fully charged would burn for some 15 h with only a moderate decrease in illumination. However, once the deep-discharge phase begins, only a few minutes of useful life remain.

If the cap lamp is turned off before the battery is fully discharged, the terminal voltage will partially recover, and enough capacity will remain to power the SRL for several days. Thus, a trapped miner can turn off the cap lamp when it begins to dim appreciably and ensure that the locator would continue to operate. By sacrificing 15 to 20 min of use of the cap lamp, the miner would obtain many extra hours of locator operation.

Under the stress of an emergency situation, a trapped miner may forget to turn off the cap lamp until the battery is too deeply discharged to recover, or might be unconscious or otherwise unable



FIGURE 15. - Transmitter placed inside cap lamp battery.

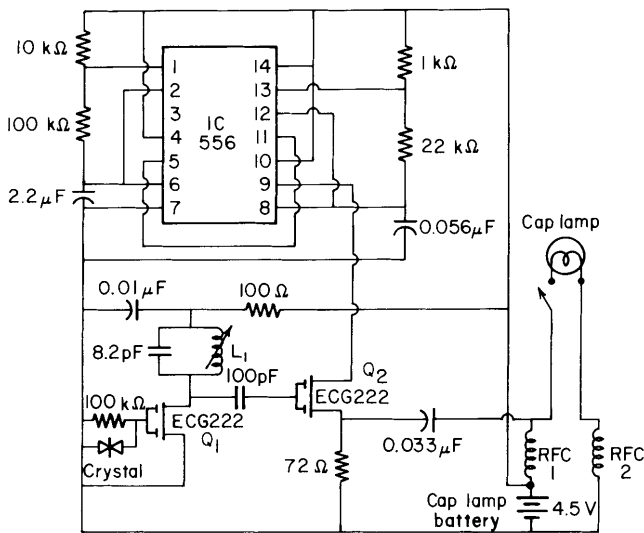


FIGURE 16. - Schematic diagram of cap lamp transmitter.

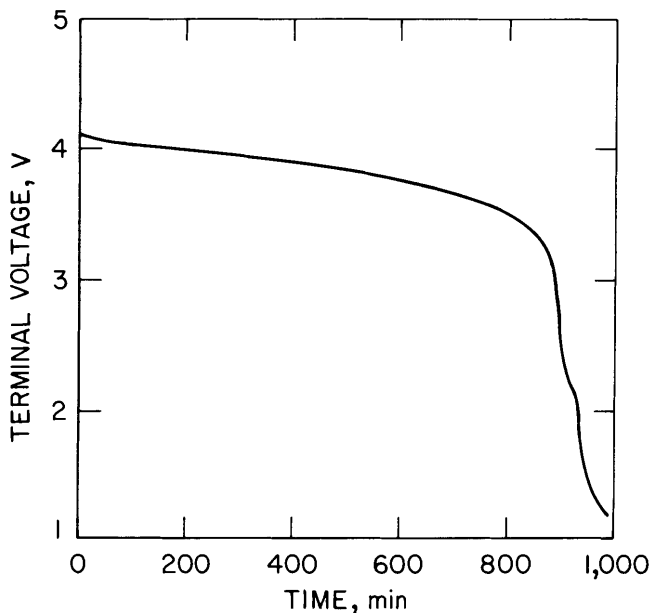


FIGURE 17. - Cap lamp battery voltage versus time of discharge.

to turn off the lamp. For this reason, a circuit could be installed to sense a low-voltage condition, which would automatically turn off the cap lamp.

The low-voltage sensor is shown in figure 18. When the battery voltage exceeds the zener voltage of zener diode  $D_1$ , current flows through  $R_2$  and  $D_1$ , biasing transistor  $Q_1$  into saturation. The gate of the silicon controlled rectifier

(SCR) is low, and the SCR is in its nonconducting (off) state. When the battery terminal voltage drops below the zener voltage, the base current to  $Q_1$  is blocked and  $Q_1$  is cut off. The SCR gate voltage goes high and the SCR fires, drawing a large current that blows the fuse, disconnecting the cap lamp. Diode  $D_2$  bypasses the fuse when the battery is being charged.

The low-voltage sensor was tested and found to operate reliably. The test setup is shown in figure 19. A computer was programmed to record the terminal voltage of the cap lamp battery and the luminous output at 5-min intervals and to record the data on magnetic tape. Thus, the test could be run unattended. Relay 1 allowed the computer to terminate the test after a preset time as measured by the internal clock. This was done to prevent damage to the battery in case the voltage sensor failed.

The battery voltage and light output for a typical test are shown in figures 20 and 21. In this test, the trigger

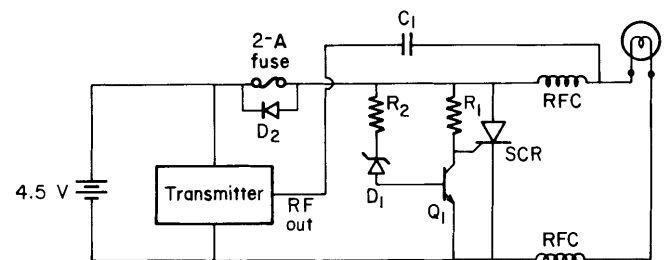


FIGURE 18. - Schematic diagram of low-voltage sensor.

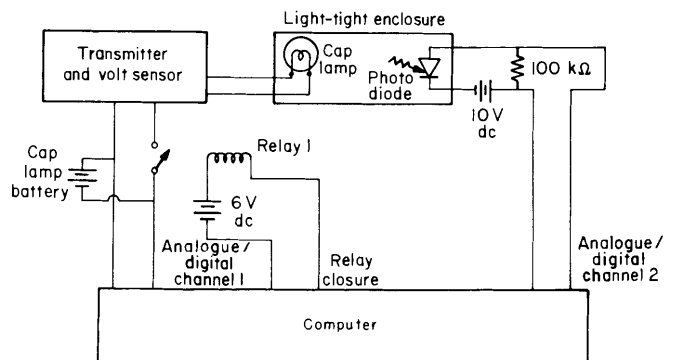


FIGURE 19. - Low-voltage sensor operational setup.

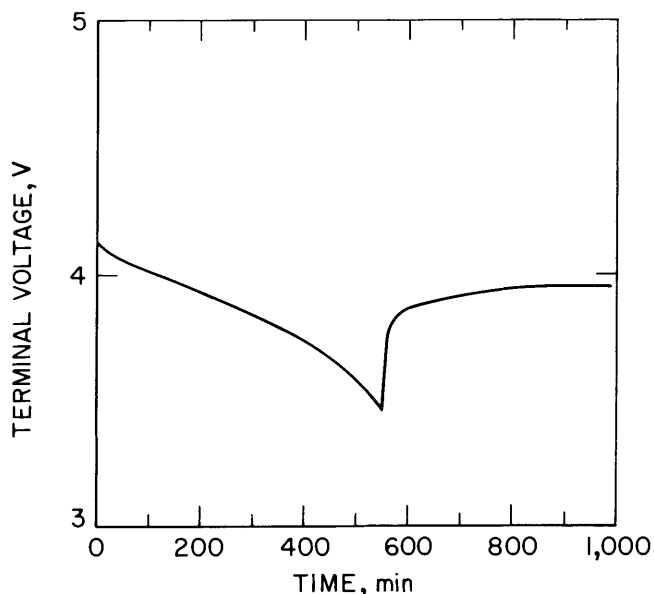


FIGURE 20. - Cap lamp battery voltage versus time with automatic shutdown of low-voltage sensor.

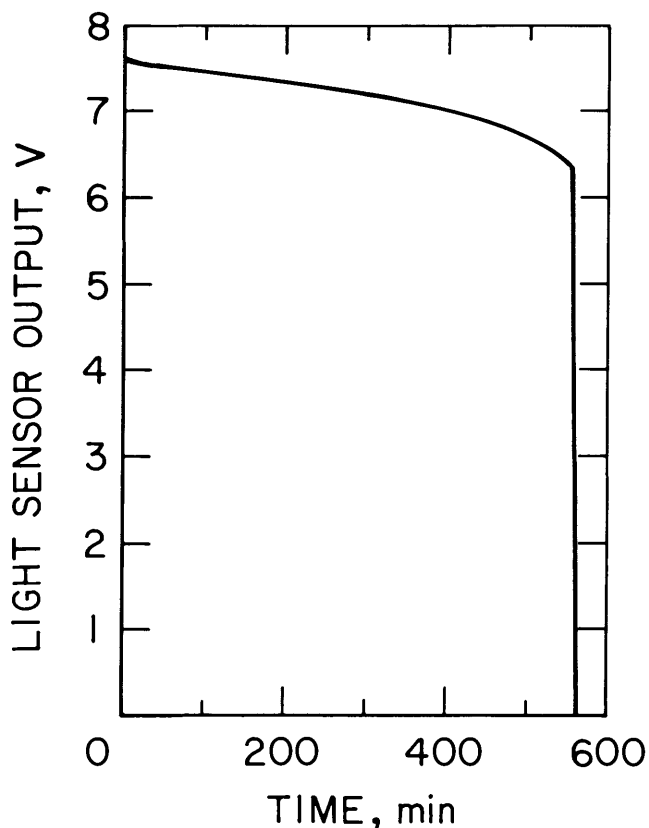


FIGURE 21. - Light sensor output volts with low-voltage sensor.

level was set at 3.5 V. Any other trigger level could be selected by using a zener diode with that voltage. A 3.25-V trigger level allowed the lamp to run for about 15 h.

The desirability of an automatic turn-off feature is open to some question. One can envision situations where an unconscious miner, whose lamp was unnecessary anyway, might be saved by extra hours of SRL operation. Scenarios can also be postulated in which a few minutes of light might be critical. It is felt that this is a question that deserves additional study.

#### PERSONAL CODING

A simple modification of the pulser circuit would allow each unit to transmit a unique pulse code so that the trapped individual could be identified. This feature might or might not be desirable. The situation might arise where a rescuer had to decide which of several trapped miners to rescue. Mine personnel who might be responsible for rescue operations have indicated that they would prefer to make such a decision without knowing the identities of the individuals involved. Concern has also been expressed that workers would fear that the locator was being used to monitor them during normal operations.

Other types of coding are also possible. For example, the short-range locator could be equipped with a selective code allowing miners to indicate that they (1) were in no immediate danger or (2) required prompt assistance. A third code would indicate that the miner had taken no action and presumably was unable to do so.

#### RESCUE TEAM UNITS

As presently perceived, all SRL's will operate on the same frequency so that a fixed-frequency receiver can be used. A second frequency should be available for use by rescue team personnel so that their locators would not interfere with search operations.

## SAFETY CONSIDERATIONS

### PERMISSIBILITY

The question of permissibility has been discussed with personnel at MSHA Laboratories, Wheeling, WV, and the MSHA field office, Birmingham, AL. Because of the low voltages and power involved, no reason is foreseen why the SRL should not be intrinsically safe.

### IGNITION OF BLASTING MATERIALS

One hazard associated with the use of any radio transmitter underground is the possibility of accidentally igniting blasting materials. Since the SRL will be carried by workers handling blasting material, the transmitter can be expected to come into close proximity to electrical blasting caps. It is therefore necessary to consider the possibility of accidental ignitions.

The no-fire level of blasting caps obtainable in the United States is 40 mW or greater.<sup>4</sup> A typical commercial blasting cap has a no-fire current of 250 mA and an internal resistance of approximately 1  $\Omega$ .<sup>5</sup> The no-fire level is therefore approximately 62 mW. The prototype SRL transmitter draws a supply current of 10 mA at 4.5 V or a total power of 45 mW. Since the output stage is a class A amplifier, the maximum theoretical

efficiency is 25 pct. The maximum radiated power is therefore less than 11 mW. Even if the blasting cap and transmitter are very close together, only a fraction of the radiated power could be coupled into the blasting circuits. It is clear, therefore, that the SRL will be incapable of igniting blasting materials.

To verify that the SRL transmitter would not ignite blasting caps, the following tests were conducted. An electrical blasting cap was connected to a pair of long wires to simulate a blasting circuit. The SRL transmitter antenna was loosely entwined with the cap's leg wires to obtain maximum coupling between the transmitter and blasting circuit. The test was repeated with three caps. None of the caps detonated. During the test, the SRL signal was monitored to verify that the transmitter was operative. All caps used in the test were later detonated electrically to ensure that they were not defective.

On the basis of these calculations and tests, it is believed that the SRL is incapable of causing accidental detonations even under the worst conditions. Before the SRL is used, additional tests should be conducted by persons familiar with the accidental ignition hazard.

## CONCLUSIONS

Test data indicated that a simple, low-cost transmitter consisting of one integrated circuit and two transistors is capable of radiating a signal through 65 ft or more of rock or through 12 ft of rock and several hundred feet of air. The transmitter can operate from a 4.5-V supply and is therefore capable

of being powered from a miner's cap lamp battery. The cost of such a unit would be low, and the unit would require no action on the part of the distressed miner. The proposed short-range locator is technically, economically, and operationally feasible, and it would substantially enhance the chances of survival of personnel trapped after a mine disaster.

<sup>4</sup>The Institute of Makers of Explosives (Atlanta, GA). Radio Frequency Radiation Hazards. Pamphlet 20, Oct. 11, 1956, 24 pp.

<sup>5</sup>Atlas Powder Co. (Dallas, TX). Handbook of Electrical Blasting. 1976, 93 pp.

Tests indicated that 27 MHz is a usable frequency for the short range locator. At frequencies above 40 MHz, the attenuation of rock is too high to allow adequate penetration, while frequencies

below 10 MHz require excessively large antennas. Additional investigation could be conducted to select an optimum frequency in the 10- to 30-MHz region.

The short-range locator can be made intrinsically safe and will pose no hazard to blasting material.

A number of optional features are possible, including various types of coding and automatic battery conservation. Additional study is required to determine if these features are desirable and to justify the additional cost.

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